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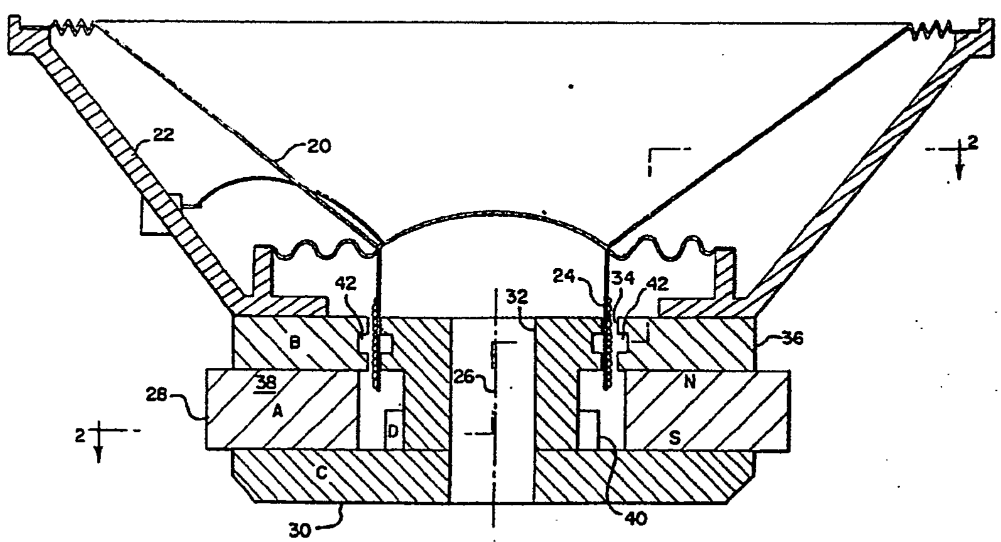

(57) Abstract

A shorted turn (42) is placed in the air gap (34) of an electromechanical transducer such as an electrodynamic speaker. The shorted turn (42) is disposed so as to couple with the same magnetic flux that acts together with current in a voice coil (24) of the transducer or loudspeaker to produce motion of a diaphragm (20) or other coupler that in turn produces pressure variations in a medium in the audible, subaudible or ultrasonic frequency ranges. In the case of a typical loudspeaker, the medium in which the pressure variations are produced is air, but that medium may equally as well be a solid, a liquid or a gas other than air, and the force produced on the coil may be used to produce mechanical vibration, agitation of a liquid or the like. Addition of the shorted turn (42) in the air gap (34) also reduces the inductance that the loudspeaker presents as a load to a driving source and it increases the fidelity of reproduction of an input signal.

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DESCRIPTION

IMPROVED ELECTRODYNAMIC LOUDSPEAKER

TECHNICAL FIELD

This invention is related to electromechanical transducers, and in particular to electrodynamic loudspeakers. It achieves an improvement in frequency response and a reduction in coil inductance as a result of a shorted turn placed in the magnetic gap of an electrodynamic speaker or the like to couple inductively to the magnetic flux lines that interact with a coil to drive the speaker.

Electrodynamic loudspeakers have in common magnets that produce magnetic flux in an air gap. The magnets are typically permanent magnets, used in a magnetic circuit of ferromagnetic material to direct most of the flux produced by the permanent magnet into the air gap. An electromagnet may also be used as the source of magnetic flux for the gap, but this is less common. The flux in the gap in the absence of current in the coil is normally constant with respect to time just as it is when it is supplied by a permanent magnet, so a permanent magnet is easier to use and is more economical.

The coil is normally connected to an audio amplifier of some type which produces a current in the coil that is a function of an electrical signal that is to be transformed by the loudspeaker into an audible,

subaudible or ultrasonic pressure variation. The coil is normally disposed so as to carry a current in a direction that is substantially perpendicular to the direction of the lines of magnetic flux produced by the permanent magnet or electromagnet. The magnetic structure is often arranged to provide cylindrical symmetry with an annular air gap in which the magnet flux lines are directed radially with respect to the access of cylindrical symmetry of the loudspeaker. The coil is placed in this air gap with its conductors wound substantially cylindrically so as to be placed perpendicular to the main component of the magnetic flux in the air gap. The coil is then connected mechanically to a diaphragm which is driven by the axial motion of the coil produced by the motor force on the coil. The coil is often referred to as a voice coil because in loudspeakers or similar electromechanical transducers the frequency range of particular interest is the extended range of the human voice. These terms will be used interchangeably here.

The utility of a loudspeaker is determined in part by its ability to translate a given electrical signal into variations in air pressure that reproduce the electrical signal. In the process of translating electrical variations in an amplifier into sound heard by a listener, many types of distortion may be introduced. Some of these, and particularly linear ones, can be corrected by techniques such as pre-emphasis, de-emphasis and the like, using techniques of linear signal processing. However, nonlinearities that lead to the formation of various harmonics are more difficult to correct in the amplifier. It thus becomes desirable to seek ways of reducing second- and third-harmonic distortion by modifying the structure of the loudspeaker.

The designer of a loudspeaker also faces conflicting choices in relating the length of the coil to the width of the air gap in which the coil is disposed. If the length of the coil is less than the width of the air gap, the coil is referred to as an underhung coil. In an underhung coil the axial motion of the coil is normally limited to the length of the gap, so that the coil never moves beyond the region in which the flux density is substantially uniform and normal to the coil. In contrast, an overhung coil extends beyond the width of the air gap when the coil is at rest. In the overhung coil, the available range of linear excursion is the distance between an end of the coil and the end of the length of the air gap. In a loudspeaker with an underhung coil, the range of linear motion is the distance between one side of the air gap and the end of the coil on that side of the air gap. The extremes of these ranges of motion are normally reached only at low frequencies. Most loudspeaker designs in current use have overhung coils. This enables the use of a relatively narrow air gap in which it is thus easier to achieve a high value of magnetic flux density with a given permanent magnet. The underhung design is also characterized by a relatively higher value of coil inductance, which interferes with the high-frequency response, and with losses in efficiency due to a relatively greater amount of energy loss due to hysteresis and eddy-current losses in the ferromagnetic material near the air gap.

The use of an underhung coil in a loudspeaker is also associated with magnetic modulation distortion which affects the linearity of response of the loudspeaker. Magnetic modulation distortion is the production of a time-dependent spatial gradient of the magnetic flux density in the gap that is caused by superposition of the

constant and substantially uniform flux density produced by the permanent magnet or electromagnet and the axial component of magnet flux produced by an AC current in the voice coil. The axial component of magnetic flux associated with the AC current in the coil alternates in direction with the direction of current flow in the coil.

One result of the distortion of the field described above is the generation of second-harmonic distortion at mid-range and higher frequencies in the axial motion of the coil. This has typically been dealt with by placing one or more shorted turns so as to link the total flux in the loudspeaker. This shorted turn is typically placed so as to encircle an axial portion of the ferromagnetic material that is a part of the pole structure of the magnetic circuit of a loudspeaker. Changes in magnetic flux in the portion of the circuit contained within the shorted turn generate an EMF that produces an induced current that produces a magnetic flux that opposes those changes.

The shorted turn described above, however, does not affect third-harmonic distortion which is associated particularly with the loudspeaker having an underhung coil, but which may also appear in an overhung design. Third-harmonic distortion must be maintained at an acceptable level in a speaker that is to produce pressure variations in air that represent an applied electrical signal.

DISCLOSURE OF INVENTION

It is an object of the present invention to provide a better electromechanical transducer.

It is a further object of the present invention to provide a better electrodynamic loudspeaker.

It is a further object of the present invention to provide an electrodynamic loudspeaker having reduced third-harmonic distortion.

It is a further object of the present invention to provide an electrodynamic speaker having improved frequency response.

These and other objects of the invention are achieved by placing a shorted turn in the air gap of an electromechanical transducer such as an electrodynamic speaker. The shorted turn is disposed so as to couple with the same magnetic flux that acts together with current in a voice coil of the transducer or loudspeaker to produce motion of a diaphragm or other coupler that in turn produces pressure variations in a medium in the audible, subaudible or ultrasonic frequency ranges. In the case of a typical loudspeaker, the medium in which the pressure variations are produced is air, but that medium may equally as well be a solid, a liquid or a gas other than air, and the force produced on the coil may be used to produce mechanical vibration, agitation of a liquid or the like. Addition of the shorted turn in the air gap also reduces the inductance that the loudspeaker presents as a load to a driving source and it increases the fidelity of reproduction of an input signal.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a front view of an electrodynamic loudspeaker for the practice of the present invention.

Fig. 2 is a sectional side view of the loudspeaker of Fig. 1, taken along section lines 2-2 of Fig. 1...

Fig. 3 is a schematic view showing relative dimensions of components of a loudspeaker having an underhung coil.

Fig. 4 is a schematic view showing relative dimensions of components of a loudspeaker having an overhung coil.

Fig. 5 is a plot of flux density B as a function of position taken along the width of an air gap in a loudspeaker that is not adapted for the practice of the present invention.

Fig. 6 is a plot of flux density B as a function of position along the width of an air gap in a loudspeaker showing the effect of using a shorted turn for second-harmonic correction.

Fig. 7 is a plot of flux density B as a function of position along the width of an air gap in a loudspeaker showing the effect of using the shorted turn of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

Fig. 1 is a front view of an electrodynamic loudspeaker for the practice of the present invention and Fig. 2 is a sectional side view of the speaker of Fig. 1, taken along section lines 2-2 of Fig. 1. In Figs. 1 and 2, a diaphragm 20 is attached to a frame 22. A voice coil 24 is attached to the diaphragm 20 so that motion of the voice coil 24 will move the diaphragm 20. The term "voice coil" is used here because it is a term in common use in referring to loudspeakers. It should be understood, however, that a loudspeaker is a particular form of electromechanical transducer, and that the output of such a device may be sub-sonic, audio-frequency or ultrasonic motion of some medium depending upon the drive that is applied to a coil such as the voice coil 24 and to the type of mechanical coupling that is made to the voice coil 24. The structure in Figs. 1 and 2 is particularly adapted to a loudspeaker having a diaphragm 20 of paper or

the like. Obvious modifications are in order if the present invention is to be practiced with a compression speaker, a mechanical vibrator, a mixer for liquids or similar apparatuses.

The loudspeaker of Figs. 1 and 2 exhibits cylindrical symmetry about an axis 26, although the structure shown is readily adaptable to oval and other noncircular cross sections. In Figs. 1 and 2 an annular permanent magnet 28 produces a magnetic flux that passes through a ferromagnetic back plate 30 and a pole piece 32 before reaching an air gap 34. In the alternative, the back plate 30 and the pole piece 32 may be combined into a single piece, or the pole piece 32 may comprise a plurality of pieces. This is a matter of design convenience for ease of manufacture or other such considerations. The top plate 36 forms one side of the air gap 34 along with the pole piece 32 and the top plate 36 is connected to the permanent magnet 28 to complete a magnetic circuit 38. Wires which are not shown here connect the voice coil 24 to a source of AC electrical energy such as an audio amplifier. Current thus produced in the voice coil 24 flows circumferentially about the axis 26 and is thus perpendicular to at least a substantial component of magnetic flux produced in the air gap 34 by the magnetic circuit 38 that is formed by the annular permanent magnet 28, the ferromagnetic back plate 30, the pole piece 32, the air gap 34 and the top plate 36. A shorted turn 40 placed about the pole piece 32 is known to reduce second-harmonic distortion. Details of this reduction will be discussed below.

Fig. 3 is a view of portions of the loudspeaker for the practice of the present invention showing an underhung voice coil 24 and Fig. 4 is a view of portions of the loudspeaker for the practice of the present

invention showing an overhung voice coil 24. In Figs. 3 and 4 the diaphragm 20 is connected to the voice coil 24, and both exhibit cylindrical symmetry about the axis 26. Only the voice coil 24, the pole piece 32, the air gap 34 and a portion of the top plate 36 of Figs. 1 and 2 are shown in Figs. 3 and 4. In Fig. 3 the voice coil 24 is shorter in the direction of the axis 26 then the width 52 of the air gap 24. This means that the voice coil 24 can travel a distance 54 without leaving the air gap 34 and thus coupling to a different value of magnetic flux density B. The fact that the voice coil 24 stays entirely within the gap 34 through a considerable range of its travel in the direction of the axis 26 provides an advantage of the use of the underhung coil as shown in Fig. 3. The corresponding disadvantage is that in order to maintain a relatively high value of magnetic flux density B it is necessary to use a relatively large permanent magnet 28 in the structure of Fig. 1, since the flux density B in the air gap 34 of Fig. 3 is given by the value of magnetic flux produced in the gap 34 divided by the area of the gap 34. This statement represents a slight oversimplification, since the air gap 34 increases in area as its radial distance from the axis 26 increases. For purposes of calculation, however, the assumption of a uniform value of flux density B in the air gap 34 equal to the value midway across the air gap 34 is usually sufficient.

The overhung voice coil 24 of Fig. 4, in contrast to the underhung voice coil 24 of Fig. 3, always has a portion of the voice coil 24 that is outside the air gap 34. Travel of the voice coil 24 of Fig. 4 is in an area of substantially uniform flux density B as long as the voice coil 24 does not travel more than a distance 56 in one direction or a distance 58 in the other. Another

way of expressing this is to say that the flux linkages with the voice coil 24 will be essentially constant as long as the travel of the voice coil 24 is less than or equal to the distance 56. It is possible, although not necessary, to make the distance 56 equal to the distance 58. The advantage of the design using an overhung voice coil 24 as shown in Fig. 4 is that the width 60 of the air gap 34 can be less than the width 52 of Fig. 3 for the same value of flux density B in the air gap 34. This makes it possible to use smaller permanent magnets 28 of Figs. 1 and 2 in the embodiment of Fig. 4 than in the embodiment of Fig. 3.

In either the underhung or overhung voice coil of Figs. 3 and 4, the shorted turn 40 may be used to reduce second-harmonic distortion. The effect of such a coil 40 will be shown graphically below. However, its use still leads to third-harmonic distortion. The present invention corrects for the third-harmonic distortion by inserting a shorted turn 42 in the air gap 34 as shown in Figs. 1 and 2. The shorted turn 42 generates an EMF that induces a current that corrects the distortion of the flux density B in the air gap 34. This also contributes to a reduction of the inductance presented by the voice coil 24 to an external amplifier or other driving source. Details of the flux changes produced by the shorted turns 40 and 42 will be shown in Figs. 5-7.

Fig. 5 is a plot of flux density B as a function of distance across the width of the air gap 34 of Fig. 1 in a loudspeaker that does not have either a shorted turn 40 or a shorted turn 42. Fig. 5 shows three curves of flux density B in the air gap 34. Curve 66 shows the flux density B when there is no current in the voice coil 24 of Figs. 1 and 2. It can be seen that the curve

has a flat top. Curve 68 shows the flux density B when current in the coil is at a maximum in one direction and curve 70 shows it at a maximum current in the other direction. The curves 68 and 70 are essentially straight lines in the air gap 34 that pivot about the value of the flux density B at an end of the air gap 34. Since the areas under the curves 66, 68 and 70 are different, harmonic distortion is introduced.

Fig. 6 is a plot of flux density B as a function of position in the air gap 34 with a shorted turn 40 in place. Curve 74 shows the flux density B with no current in the voice coil 24, curve 76 shows it with current at a maximum value in one direction, and curve 78 shows it at a maximum in the other direction. It can be seen that introduction of the shorted turn 40 has moved the pivot point to the center of the gap but has allowed the curves to pivot about the value of flux density B in the middle of the air gap 34. The areas under the three curves 74, 76 and 78 are equal but the curves are not at a constant value of flux density. B.

Fig. 7 is a plot of flux density B as a function of position in the air gap 34 for all values of current in the voice coil 24 with both a shorted turn 40 and a shorted turn 42 in place. Curve 82 is a plot of the resulting flux density B, which is constant for all values of current in the voice coil 24. This has resulted from the addition of the shorted turn 42 in the air gap 34. This essentially eliminates the third-harmonic distortion that remains after introduction of the shorted turn 40. The result is to reduce distortion in the output of the loudspeaker. It also reduces the amount of inductance presented by a loudspeaker having such a shorted turn 42.

The preceding description is intended to illustrate the preferred embodiment of the invention. It

is intended to illustrate and not to limit the scope of the invention, which extends to the breadth of the appended claims.

CLAIMS

1. An electromechanical transducer comprising:
   a. an air gap;
   b. means for producing magnetic flux in the air gap;
   c. a coil disposed in the air gap so as to carry a current in a direction substantially perpendicular to the magnetic flux;
   d. a diaphragm connected to the coil and suspended so as to move in response to a force exerted on the coil; and
   e. a shorted turn of an electrical conductor disposed in the air gap.

2. The electromechanical transducer of claim 1 wherein the air gap is substantially annular about an axis of cylindrical symmetry.

3. The electromechanical transducer of claim 2 wherein magnetic flux produced by the means for producing magnetic flux is directed substantially radially with respect to the axis of symmetry.

4. The electromechanical transducer of claim 2 wherein the coil and the shorted turn are disposed substantially in cylindrical symmetry with respect to the axis.

5. A loudspeaker comprising:
   a. an air gap;
   b. means for producing magnetic flux in the air gap;

c. a voice coil disposed in the air gap so as to carry a current in a direction substantially perpendicular to the magnetic flux;

d. a diaphragm connected to the voice coil and suspended so as to move in response to a force exerted on the voice coil; and

e. a shorted turn of an electrical conductor disposed in the air gap.

6. The loudspeaker of claim 5 wherein the air gap is substantially annular about an axis of cylindrical symmetry.

7. The loudspeaker of claim 6 wherein magnetic flux produced by the means for producing magnetic flux is directed substantially radially with respect to the axis of symmetry.

8. The loudspeaker of claim 6 wherein the voice coil and the shorted turn are disposed substantially in cylindrical symmetry with respect to the axis.

9. The loudspeaker of claim 5 comprising in addition a frame connected to the means for producing magnetic flux.

10. The loudspeaker of claim 9 wherein the diaphragm is suspended from the frame so as to permit motion of the voice coil in a direction substantially parallel to the axis.

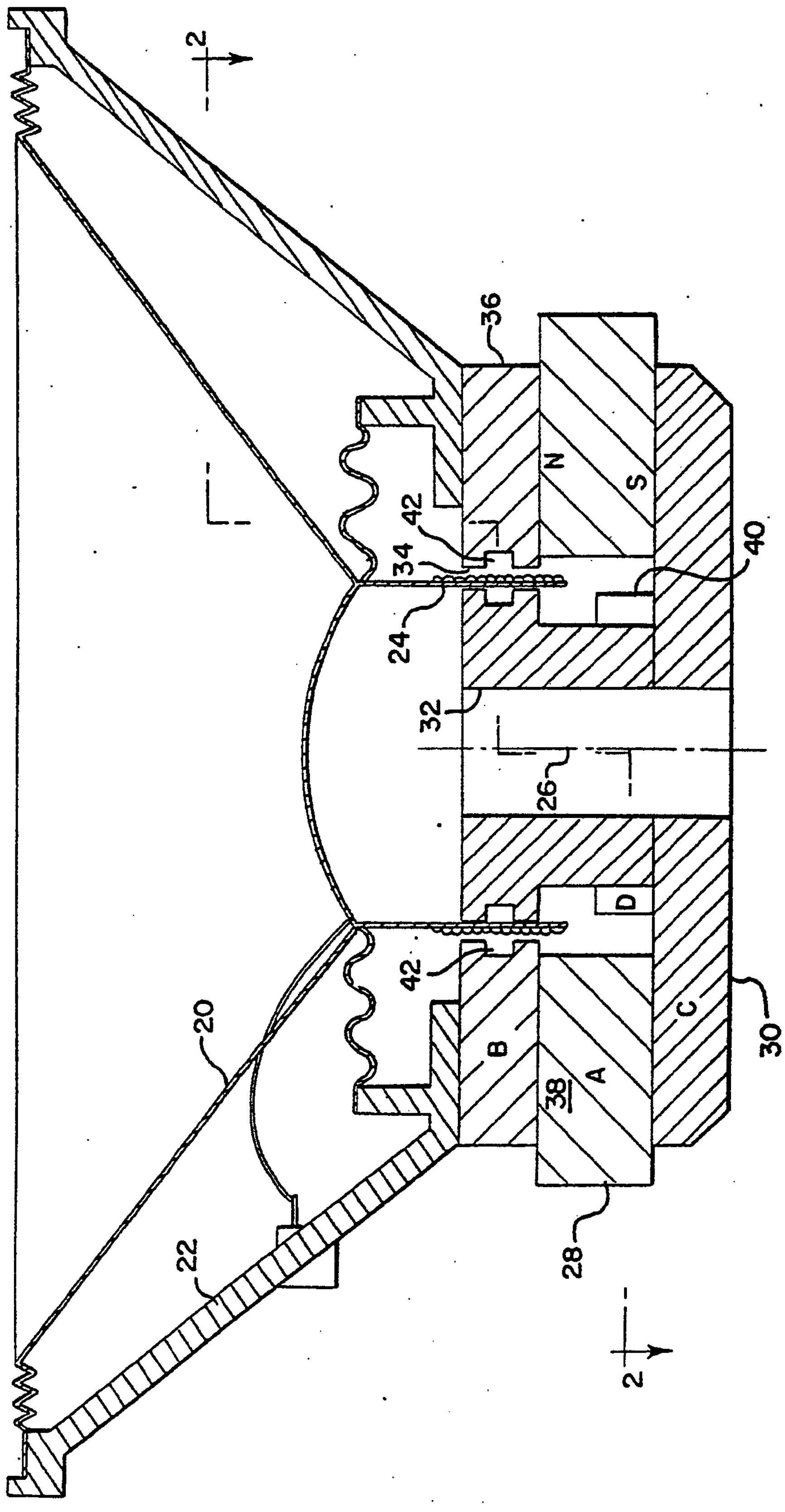

FIG. 1

FIG-2-

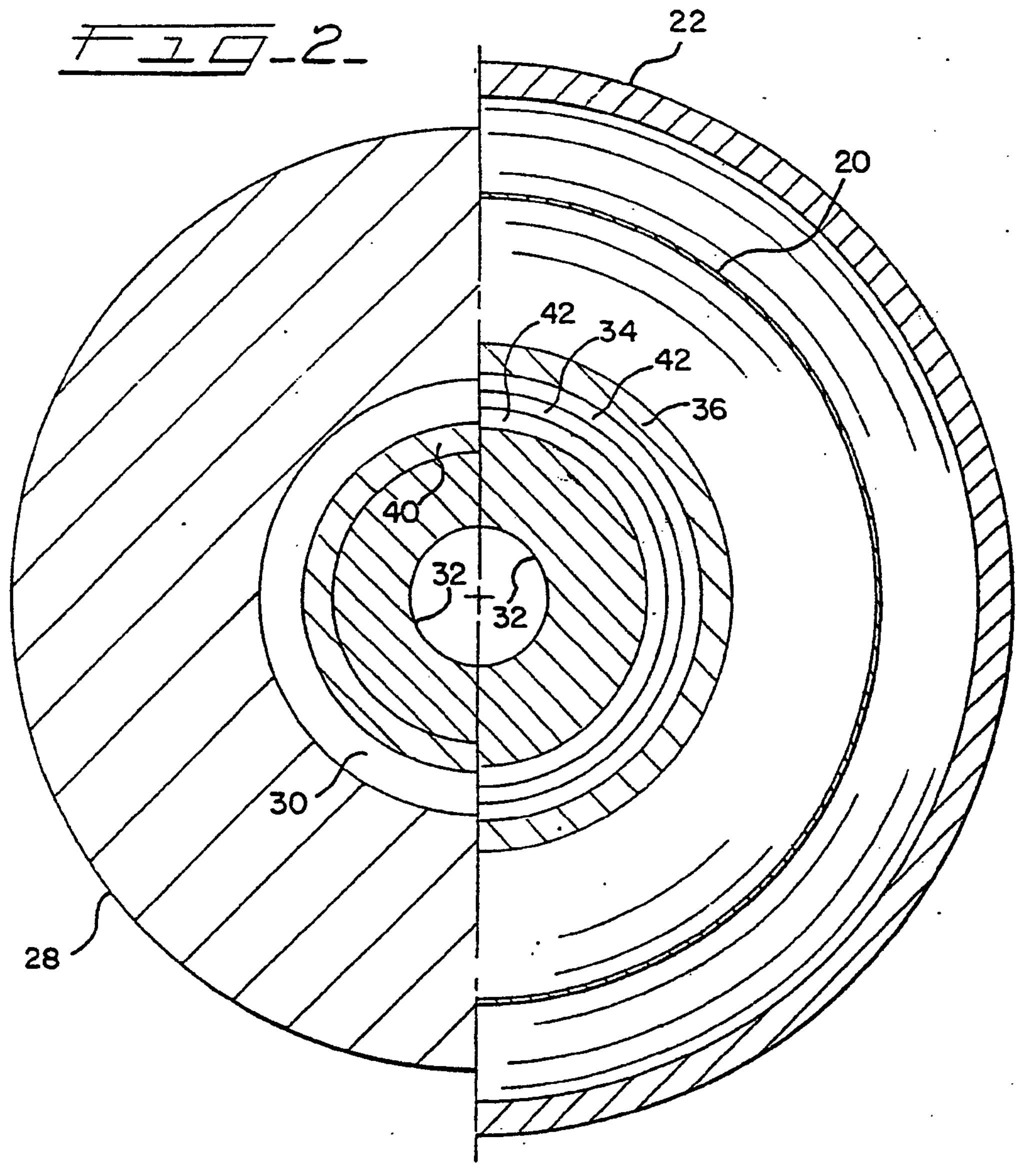

FIG_3_

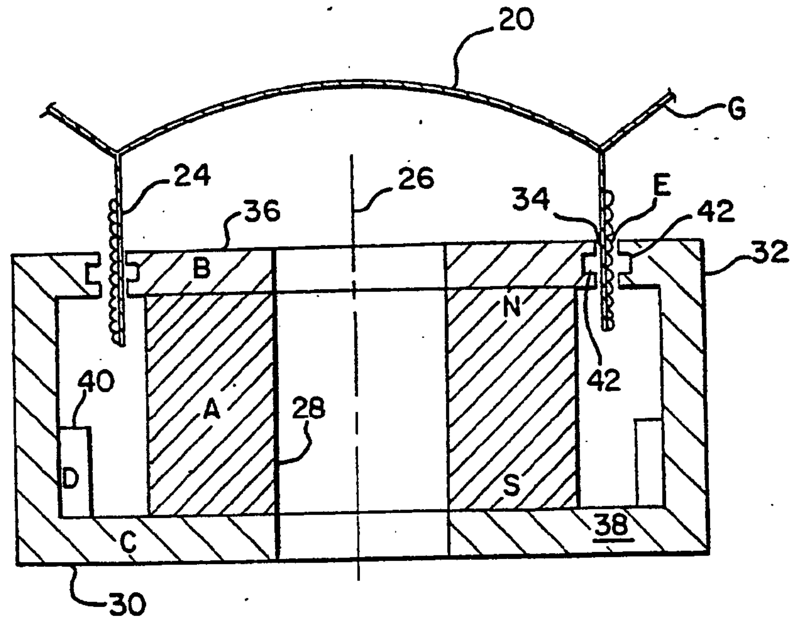
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FIG_4_

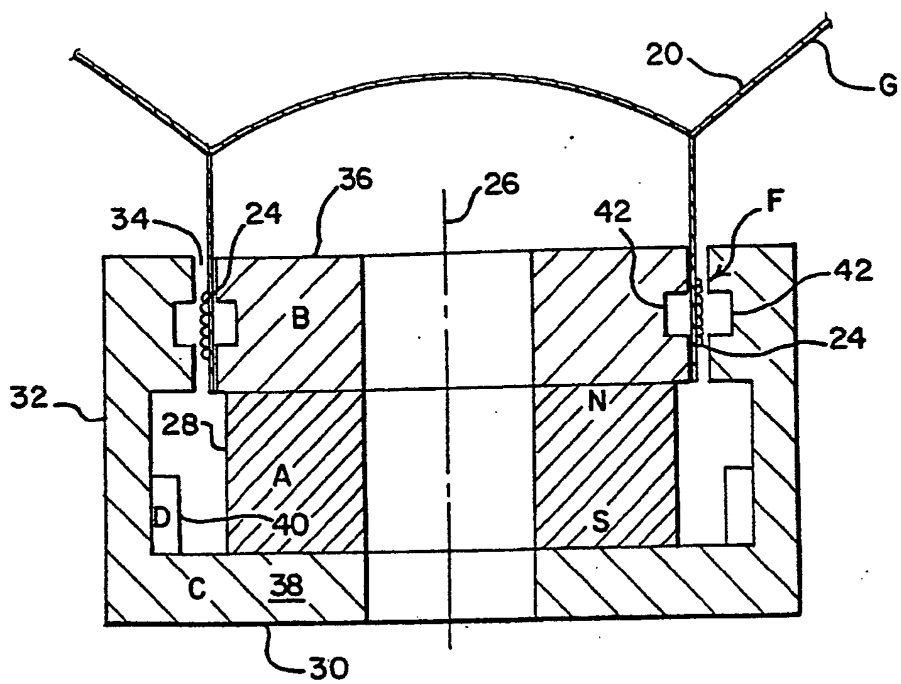
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FIG-5

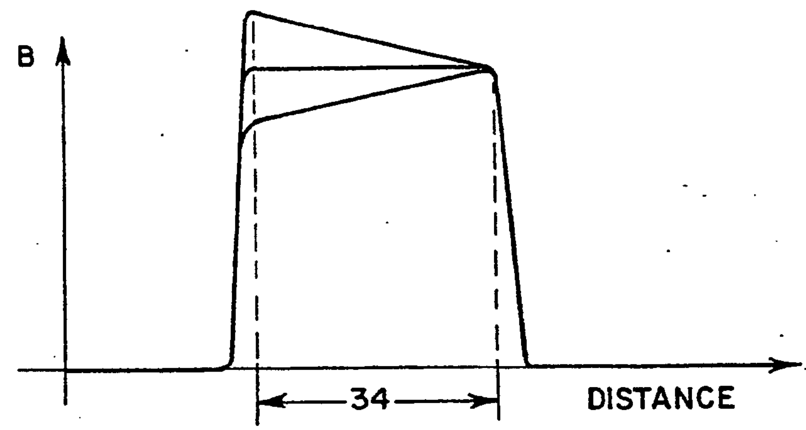


FIG-6

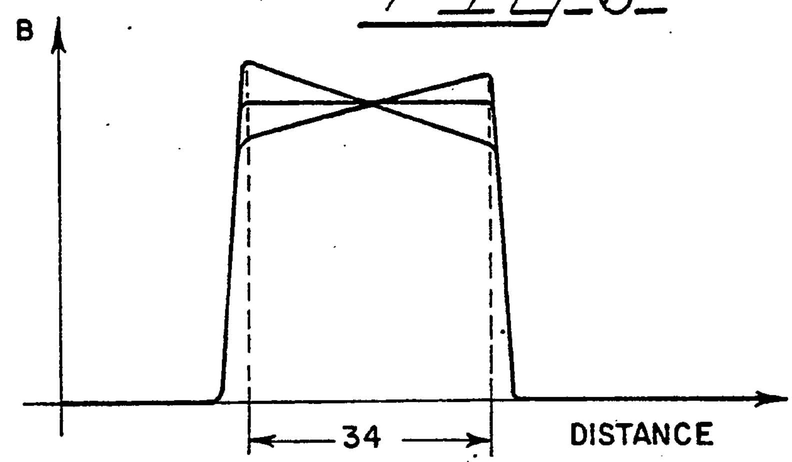
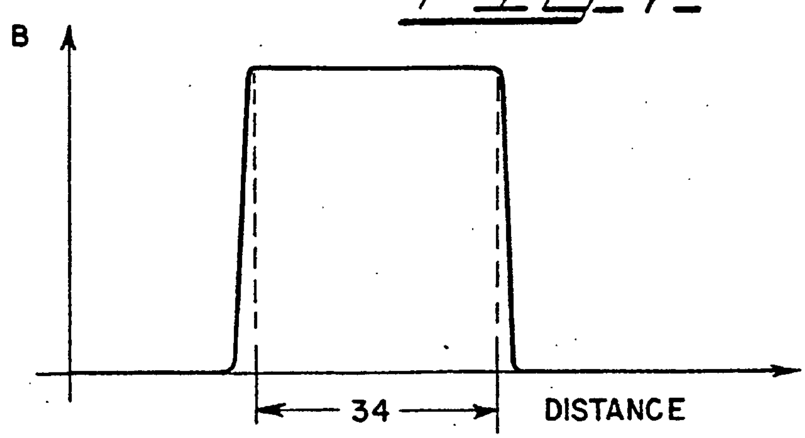


FIG-7



INTERNATIONAL SEARCH REPORT

International Application No PCT/US90/05551

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5): H04R 25/00 US CL.: 381/186,187,194,195,199

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
US	381/194,195,199,187,186

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	WO 81/02501 (SAKAI) 03 September 1981 See abstract and figs. 7 and 12.	1-8
Y	US, A, 3,783,311 (SATO et al.) 01 January 1974 See fig. 2.	9-10
A	US, A, 4,289,937 (IKEDA et al.) 15 September 1981 See fig. 1.	1-10

* Special categories of cited documents: [15]

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IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
16 JANUARY 1991	14 FEB 1991
International Searching Authority [1]	**Signature of Authorized Officer** [20]
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